National Aeronautics and Space Administration

RADIOISOTOPE
POWER SYSTEMS

Analysis of RPS-Powered Flown Missions and Studied Mission Concepts for Next-Generation RTG Study

Brian Bairstow
Systems Engineer, RPS Mission Analysis
Jet Propulsion Laboratory, California Institute of Technology

Young Lee, Knut Oxnevad

2/27/2018

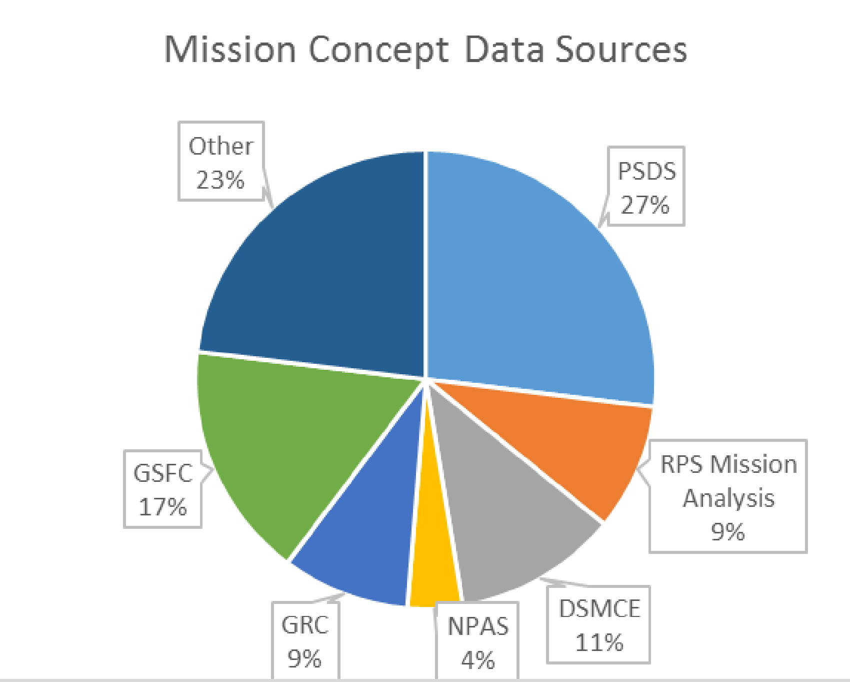
POWER TO EXPLORE

Next-Generation RTG Study

- The Next-Generation RTG study was carried out in 2016-2017 to determine the characteristics of options for a new RTG that would best fulfill NASA Planetary Science Division (PSD)’s upcoming mission power needs, examining the applicability to various exploration targets and mission class and types
- The RPS Program Mission Analysis Team supported the study by examining the applicability to various exploration targets and mission class and types
  – Identify draft NASA Planetary Science Division (PSD) mission requirements
  – Examine the existing PSD mission concepts to various destinations across the solar system, mission concepts studied by various organizations and missions flown
  – Assess the mission impacts to a notional Next-Generation RTG power system

RPS Mission Concepts Analyzed

- The mission analysis team gathered RPS-powered mission concepts from several sources:
  - 2011 Planetary Science Decadal Study (PSDS) studies
  - RPS Program Mission Analysis studies
  - Curated data from the 2007 Discovery and Scout Mission Capabilities Expansion (DSMCE) studies
  - Data contributed for the 2014 Nuclear Power Assessment Study (NPAS)
  - Summary of RPS studies provided by Glenn Research Center (GRC) COMPASS Team
  - Summary of RPS studies provided of Goddard Space Flight Center (GSFC) Mission Design Lab
  - Other publically available mission concept studies conducted for NASA and flown and in-development missions



- In total, 77 RPS spacecraft and associated mission studies were evaluated and assessed for the Next-Generation RTG Study

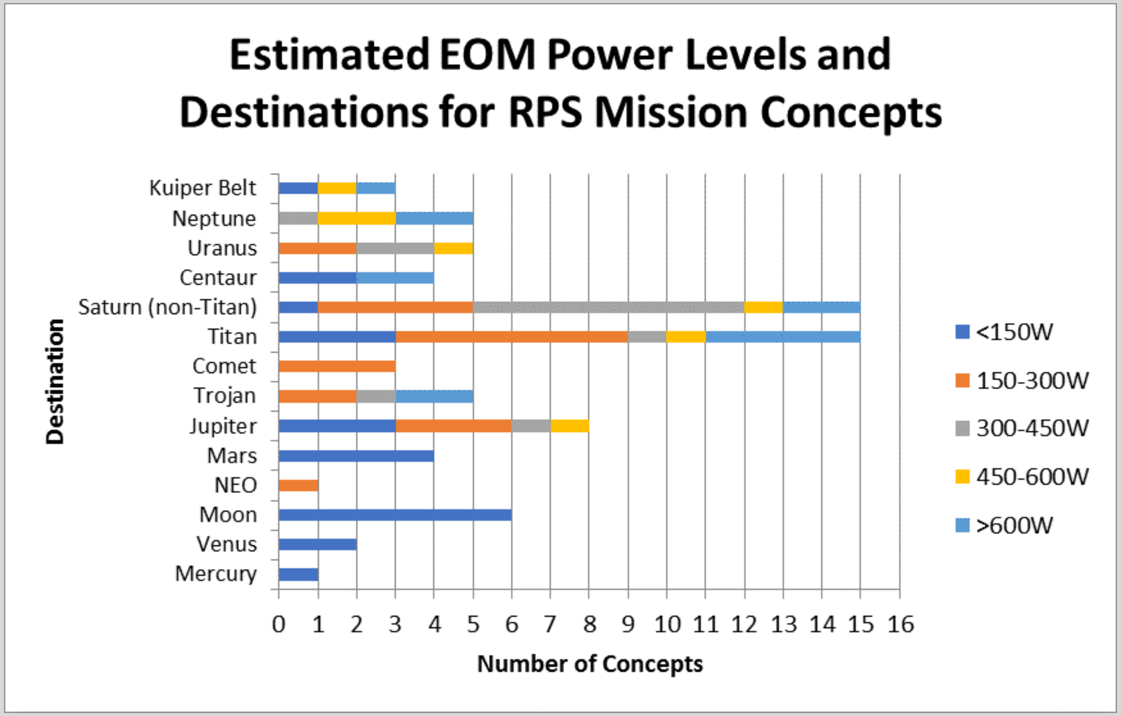
Mission Analysis Database

- To perform the required analyses and to combine data and present the results in a unique way, an extensive relational database was developed
- The 77 RPS-powered mission concepts examined cover a range of targets, power levels, mission types, mission durations, and mission classes
  - These 77 flight systems performed a total of 125 “missions”, where mission is defined as a unique vector of spacecraft, mission type (e.g., lander) /subtype (e.g., rover), and target
    - For example, Cassini conducted flybys of Enceladus and 2685 Masursky, and orbited Saturn, which is considered three missions under this definition
  - Actual flown missions were also included in the database

Number of Analyzed Targets	**63**
Total missions used in this study	249
Flown missions reviewed in the study	124
Studied mission concepts in the study	125
Total missions used in this study	249
Flyby missions (flown and studied)	102
Orbiter missions (flown and studied)	72
Atmospheric probe missions (flown and studied)	10
Aerial missions (flown and studied)	4
Surface missions (flown and studied)	54
Subsurface missions (flown and studied)	1
Sample return missions (flown and studied)	6

Mission Concepts by Destination

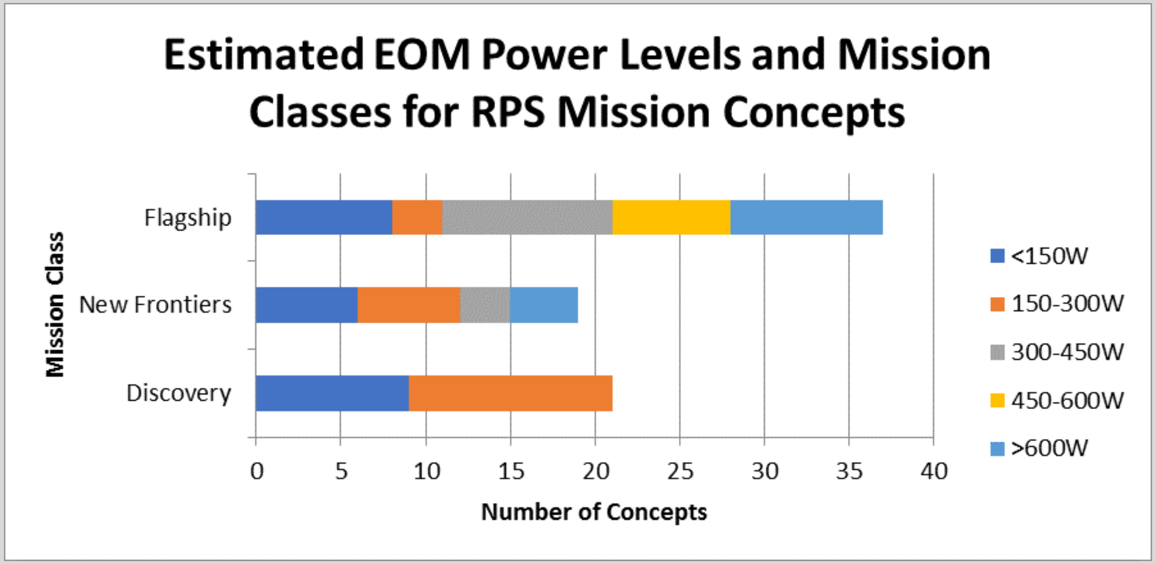
- The 77 RPS-based mission studies examined for this analysis cover a range of targets and power levels
  - Titan missions are broken out from the other Saturn system missions, due to the unique environment and high interest



  - Altogether, 30 Saturn system mission concept studies were reviewed
    - Missions to targets closer than Saturn can often be accomplished using solar power
    - Missions to targets farther than Saturn have challenges including:
      - Constrained launch masses
      - Limited data return
      - Need for large delta-Vs
      - Long travel times causing degradation in power output

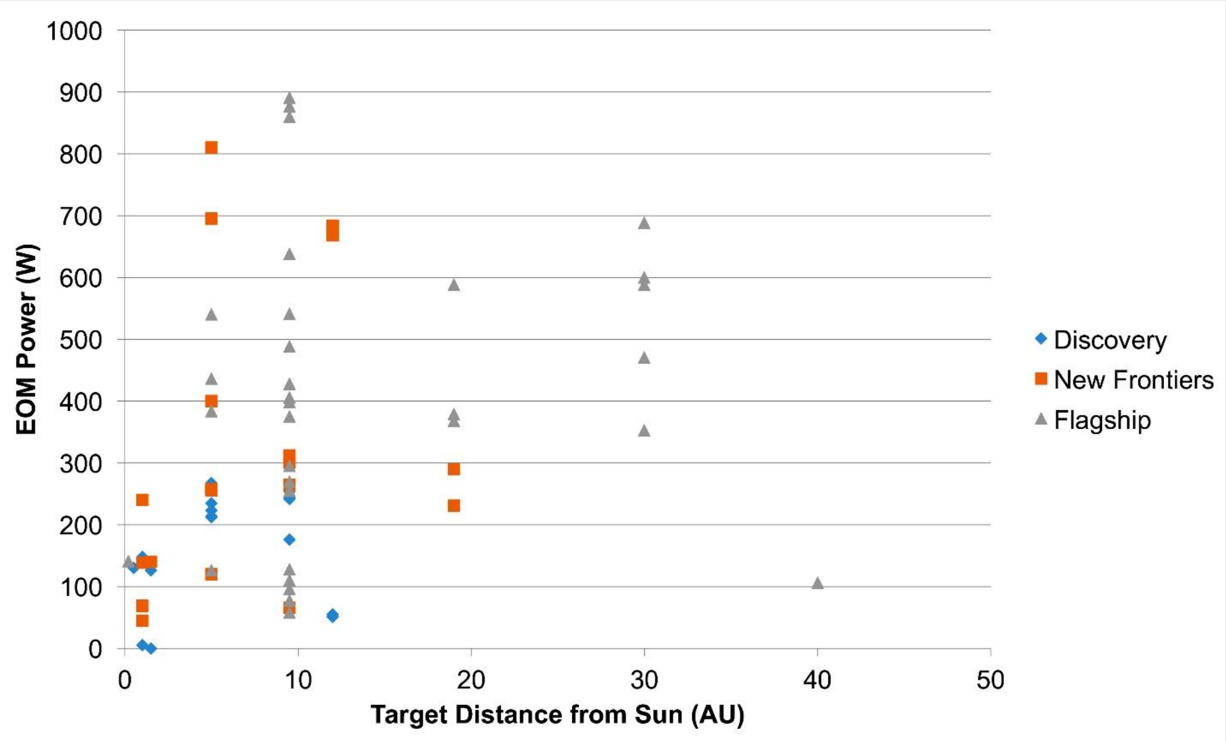
Mission Concepts by Mission Class

- The 77 RPS-based mission studies can also be sorted by mission cost class
  - Discovery-class missions are extremely resource-constrained, making them especially sensitive to mass and power generation values for RPS units



  - New Frontiers-class missions are also resource-constrained, though not so much as Discovery-class missions
  - Flagship-class missions generally need more power to operate ambitious investigations with large payloads and high data return requirements
- Nearly half of the mission concepts that could require RPS are in the flagship class, which reflects the challenges in accommodating RPS

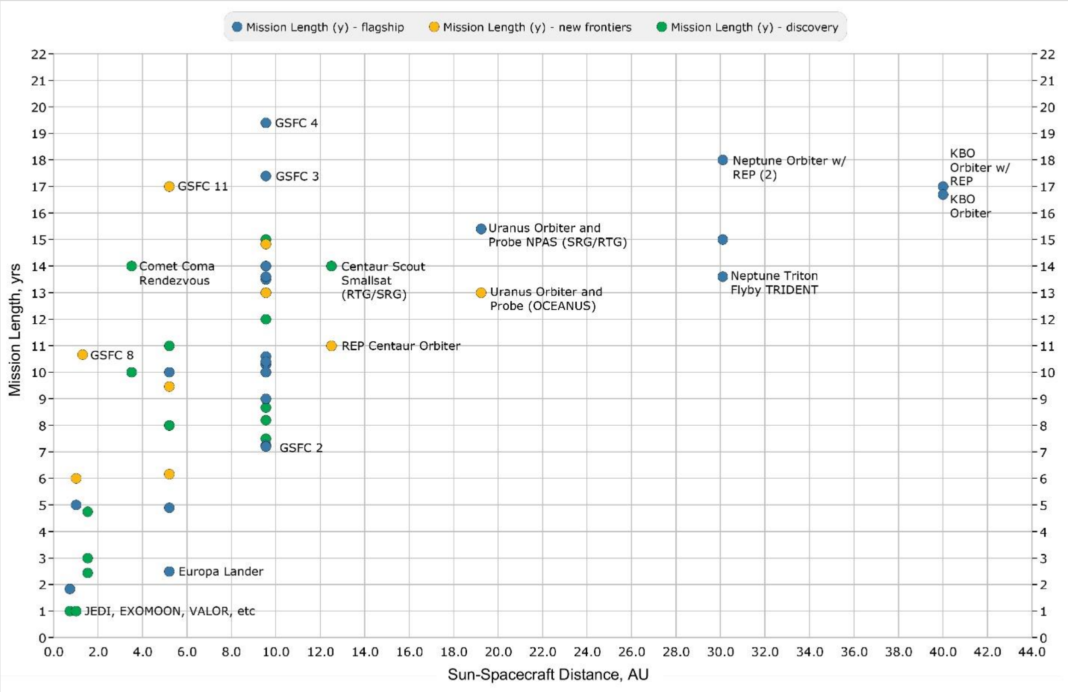
Mission Concepts – Distance and Power



- Discovery-class RPS missions go as far as 12 AU (a Centaur SmallSat study), and generally tend towards lower Sun-spacecraft distances
- The New Frontiers-class RPS missions do not make it past 19 AU (Uranus)

- 60% of studied missions have power needs <300 W_e EOM
- 77% of studied missions have power needs <550 W_e EOM
- 92% of studied missions have power needs <820 W_e EOM

Mission Concepts – Distance and Duration

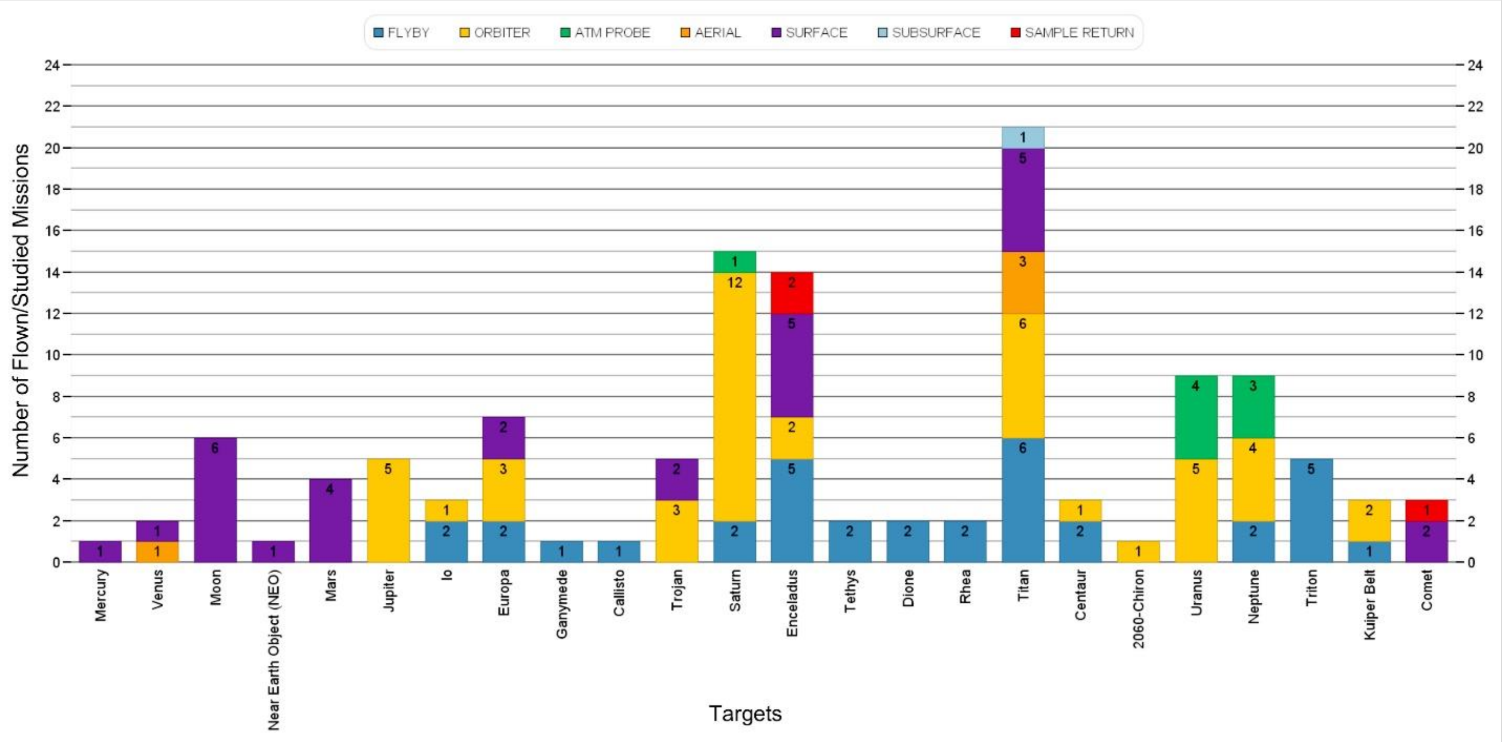


- Mission lengths for studied missions
  - Mars, Venus, and the Moon are 1–11 years
  - Jupiter at 5 AU is 2.5–17 years
  - Saturn at 10 AU is 7–19.3 years
  - Uranus at 20 AU is 13–14 years
  - Neptune at 30 AU is 13.5–18 years
  - KBOs at 40–44 AU are ~17 years

- Minimum mission length nearly doubles, 7 to 13 years, when comparing Saturn mission studies with Uranus mission studies
- Mission length stays in the same range for studies of missions to Uranus and Neptune
- Mission length then increases again from 13.5 to 16.5 years when going to the Kuiper Belt

- The figure shows the maximum mission length for the studied RPS missions by class are: 14 years for Discovery, 17 years for New Frontiers, and 19.3 years for Flagship

Studied Missions – Types by Destination



- The chart includes secondary targets for a total of 125 studied missions
- Mostly surface mission concepts for destinations < 5 AU from the Sun
  - Orbiter/flyby missions could generally use solar power
  - Landed missions may not be able to use solar power due to shadowed regions, atmospheric conditions, or long night times or where carrying solar arrays may make a mission impractical
- There is also significant interest in Enceladus and Titan lander missions
  - Titan stands out in general, with interest in flybys, orbiters, and in situ missions exploring Titan's atmosphere, surface, and lakes

Requirements Findings – Power

- Power needs for the studied spacecraft and associated missions range from less than 10 W_e to more than 1000 W_e at EOM
  - 60% of the missions have power needs below 300 W_e at EOM, 77% below 550 W_e at EOM, and 92% below 820 W_e at EOM
- To serve all reasonable mission concepts with one unit, a Next-Generation RTG would have to produce 820 W_e total at EOM
  - This unit would be too large and massive for most missions requiring less power
- A Next-Generation RTG producing 200-300 W_e total at EOM could meet most mission power needs with 4 or fewer total units
  - Flying multiple units comes with a penalty to mass and complexity of configuration and integration
  - 200-300 W_e would still make for large, discrete steps in generated power
- A modular Next-Generation RTG could be procured in a variety of sizes more closely matched to the power needs of the greatest number of missions

Requirements Findings – Mission Length

- The existing MMRTG has a requirement to operate for 17 years once fueled
  - With a storage period of up to three years before liftoff, this translates into a flight life of 14 years
- Of the missions studied, 70% have a flight lifetime less than this.
  - The longest mission concept has a flight lifetime of 19.4 years
- Since mission flight durations are expanding (for instance for ice probes), Next-Generation RTGs should consider total operational lifetimes of 20–24 years
  - Should not be a major design obstacle as RTGs are given to graceful degradation
  - Could require additional testing and qualification of the thermoelectric couples and materials (e.g. insulation)
  - Development cycle could take longer due to testing

Requirements Findings – Environment

- Of the 77 studied RPS-powered mission concepts:
  - 40 are flybys and orbiters, requiring a power system that only needs to operate in the vacuum of space
  - 37 are aerial, surface, subsurface, and sample return mission types
    - 16 of these are to targets with an atmosphere
    - 21 are to targets without an atmosphere
- This means that nearly 80% of the missions studied only need a power system that can operate in the vacuum of space
  - Next-Generation RTG would be very similar to a GPHS-RTG in this regard
  - A pressure vessel would be a potential solution to use Next-Generation RTG at a destination with an atmosphere or for subsurface exploration

Conclusions

- The RPS Program Mission Analysis Team gathered 77 RPS-powered mission concepts
- These mission concepts were used to determine which potential RPS concepts would be applicable to many future missions, using the missions' power levels as inputs for the analysis
- The mission analysis work helped define the preliminary requirements documented in the Next-Generation RTG Study final report

Questions?